SOLENOID AND SYNCHROTRON RADIATION EFFECTS IN CLIC

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Abstract

The emission of Synchrotron Radiation in the CLIC BDS is one of the major limitations of the machine performance. An extensive revision of this phenomenon is presented with special emphasis on the Interaction point (IP) solenoid.

INTRODUCTION

The emission of Incoherent Synchrotron Radiation (ISR) in the CLIC BDS results in an increase of the beam emittance (and as a consequence the IP beam spot size), due to the incoherent energy spread generated by the quantized radiation emitted by the bent high energy beam. In addition, if the energy spread of the incoming beam is large the full compensation of the chromaticity cannot be achieved, this results in an increase of the IP spot size too. Therefore incoherent synchrotron radiation gives a limit in the maximum luminosity achievable by limiting the minimum beam spot size at the IP.
Furthermore due to the crossing angle (θ_c) between the beam axis and the solenoid longitudinal axis the beam encounters a nonzero vertical bending (y-plane) as it travels in the solenoid detector field. Then it can emit ISR in the detector solenoid field.
A detailed study of the ISR effects in the CLIC-BDS is reported in [1]. This paper summarizes the results from [1] and in addition presents details on ISR studies due to the detector solenoid magnetic field as well as its superposition with the last magnets in the Final Focus System (FFS).

INCOHERENT SYNCHROTRON RADIATION IN THE BDS

In order to study the impact of the emission of ISR due to CLIC-BDS lattice (L^* = 3.5 m) we have estimated the horizontal emittance growth due to ISR and we have evaluated the relative luminosity loss due to ISR. The emittance growth for CLIC has been evaluated using the codes BETA [2] and DIMAD [3], used for the ILC ISR estimates and compared with PLACET [4]. We found a good agreement for ISR estimates using these codes for the beam without energy spread and with 0.4% Gaussian energy spread [1].
To estimate the ISR effect on the relative luminosity, the beam was tracked in the BDS with PLACET, with and without ISR and then GUINEA-PIG [5] was run for luminosity calculations. The relative luminosity loss due to ISR in the full BDS is about 24%.

The relative luminosity loss due to incoherent synchrotron radiation, using the nominal CLIC beam with 1% flat energy spread, is reported in Table 1. By switching on and off the synchrotron radiation in the different type of elements of the CLIC BDS (i.e. quadrupole, bending magnets and multipoles), we found about 10% luminosity loss due to ISR in the bending magnets, no significant luminosity loss due to ISR in the multipole and about 10% luminosity loss due to ISR in the quadrupoles, which comes from the final doublet. Moreover we found that the luminosity loss due to the final doublet is not fully explained by the well known Oide Effect [1].

Table 1: Relative luminosity loss due to Incoherent Synchrotron Radiation (ALL ISR ON). Relative luminosity loss due to the Incoherent Synchrotron Radiation in the different type of magnets of the CLIC BDS are shown too.

	L/L_0
ALL ISR OFF	1.00 ± 0.02
ALL ISR ON	0.78 ± 0.02
ISR QUAD ON only	0.90 ± 0.02
ISR MULTI ON only	1.00 ± 0.02
ISR SBEND ON only	0.86 ± 0.02
ISR QF1+QD0 OFF only	0.87 ± 0.02
ISR QF1+QD0 ON only	0.90 ± 0.02

INTERACTION REGION SOLENOID

The detector solenoid fields at the interaction region have different effects on the beam dynamics [6, 7]:

- weak focusing in the two transverse planes;
- orbit deviation: the beam is bent as it traverses the magnetic field;
- coupling between the x-y plane: the particle position in one plane depend from the position in the other plane;
- dispersion: particles at lower energies experience a larger deflection than those at higher energies;
- the beam emits ISR as it is deflected.

The focusing and coupling between the two transverse planes are due to the radial component of the solenoid field which is $\propto$ r. The orbit deviation and dispersion are due to both the longitudinal and radial component of the field. The size of the deflection depends on the crossing angle value, on the length and on the maximum field value. The dispersion depends on the incoming beam energy spread. Finally the emission of ISR is a consequence of the beam deflection as already mentioned in the introduction. The last three effects all together contribute to the increase of the IP spot sizes. In particular for an horizontal crossing angle as the one considered in CLIC, these effects lead to the increase of the IP vertical beam size.

A preliminary study indicates that the IP spot size growth due to ISR for B_z = 4 T and a crossing angle of θ_c = 20 mrad is still acceptable [8]. However, the results depend significantly on the detector end fields, for which only a simple model was used in this study.
A "realistic solenoid magnetic field" model includes a real description of the solenoid stray fields and the explicit consideration of both its extension inside the final magnets of the FFS and the tilted solenoid reference system with respect to the beamline.
In order to take into account a realistic solenoid model in the interaction region beam dynamics, we have written a tracking program which reads a magnetic field map from an external file. It tracks the particles in the solenoid field and through the final magnets of the FFS, taking into account the possible overlaps of the fields, and the CLIC nominal crossing angle $\theta_c/2$=10 mrad. It also includes the Monte Carlo simulation of the incoherent synchrotron radiation implemented in PLACET.
The external map considered for this paper is the simulated SiD detector solenoid magnetic field which has a maximum longitudinal magnetic field B_z = 5 T [9].

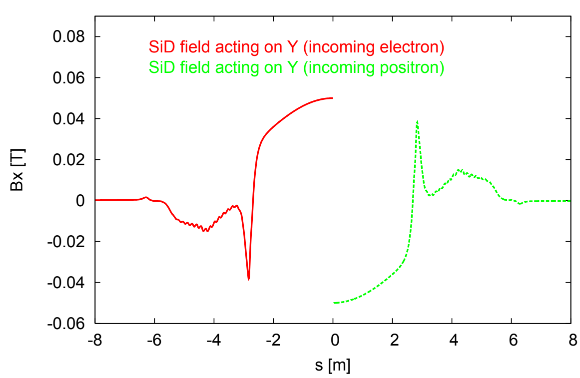

Figure 1: SiD fields acting on the vertical plane for an incoming electron (red-full line) and for an incoming positron (green-dashed line). IP is at s = 0 m. B_x and s are in the beamline reference system.

Figure 1 shows the fields acting on y-plane resulting by the longitudinal and radial component of the SiD magnetic fields. Since the magnetic field map is calculated on the ideal ILC beamline with half crossing angle of 7 mrad, we have scaled linearly the B_r component of the field to the CLIC crossing angle, keeping constant the longitudinal component (*i.e.* homogenuos longitudinal field). This simulation of the SiD magnetic field does not take into account possible distortions of the field due to the end-cap or to the shielding of the beamline magnets. As can be easily seen from the plot, part of the solenoid field extents over the QD0 (which is at $\sim 3.5 < |s| <\sim 6.9$ m).

Figure 2 shows the trajectories of an incoming electron (red-full line) and an incoming positron (green-dashed line) in the horizontal and vertical plane of the SiD solenoid reference system (where the IP is at z = 0). This figure shows a vertical offset of the two beams at the IP, which is due to

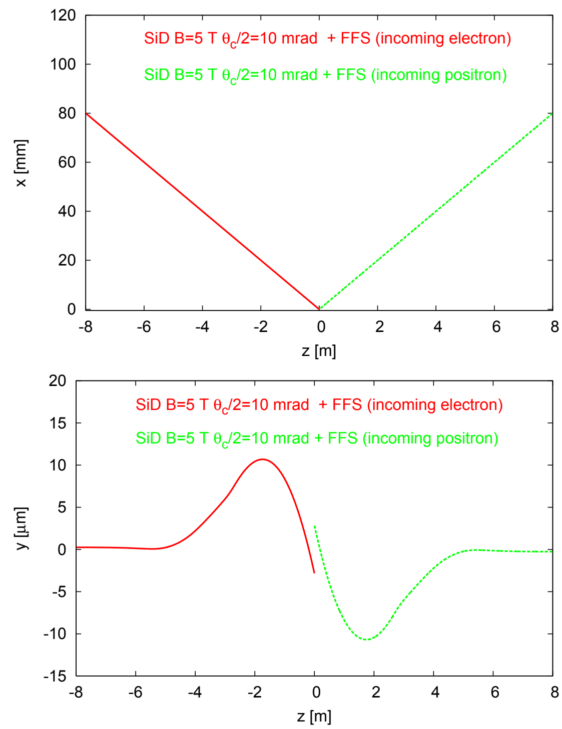

Figure 2: Electron (red-full line) and positron (green-dashed line) reference trajectories due to the last final focus magnets and the solenoid magnetic field. The horizontal plane (top) and vertical plane (bottom) are shown in the solenoid reference system.

the overlap of the SiD solenoid with the final magnets of the CLIC FFS, as explained in detail in [10]. Techniques to compensate optical distortions due to the solenoid fields and their superposition with the final magnets of a linear collider can be found in [10, 11] and references therein.
These compensation techniques do not cancel out completely the orbit deflection in the interaction region. Even after the optical corrections, the beam undergoes to a deflection as it traverses the solenoid field, and as a consequence emits ISR. The actual and detailed compensation of the SiD and its superposition to the final quadrupole of the CLIC-BDS is beyond the scope of this paper. In order to have an estimation of the ISR effect, once the optical compensation has been achieved, we have backtracked the nominal CLIC beam with the average angle, shown in Fig. 2, from the IP to the solenoid field entrance in order to determine the beam offsets and the beam x-y correlations that cancel the vertical offset and the x-y coupling at IP. We tracked forward this beam to the IP taking into account the emission of ISR due to the beamline magnets and the detector Solenoid.
We have computed the luminosity, using GUINEA-PIG, and found that the emission of ISR due to the the SiD magnetic field results in a relative luminosity loss of about 4% to be added to the about 24% luminosity loss due to the BDS.
For comparison we have scaled the SiD magnetic field map

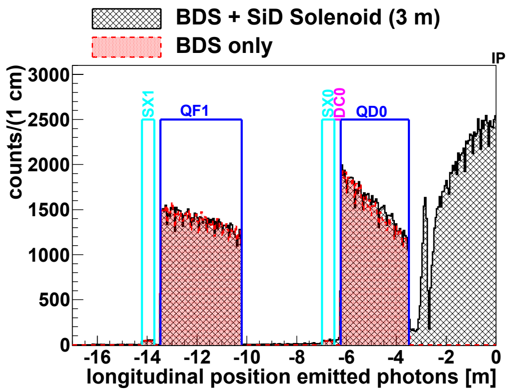

Figure 3: Longitudinal position of the emitted photons, red line are the photon emitted due to synchrotron radiation in the FFS only, black line shows the emitted photon when SiD field is superimposed.

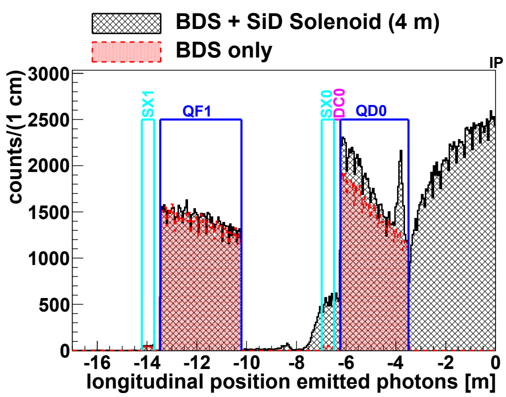

Figure 4: Longitudinal position of the emitted photons as in Fig. 3. The SiD magnetic field is scaled to fit a length of 4 m instead of 3 m.

to fit a maximum magnetic field of 4 T instead of 5 T. The relative luminosity loss in this case is about 2%.

Moreover we found that the loss is mostly due to the beam deflection in the L* region, as can be easily seen in Fig. 3. The number of photons emitted in the final doublet do not change considerably when the SiD solenoid field is taken into account. While an enhancement of emitted photons is clearly visible between QD0 and the IP.

Finally we have also scaled the SiD map to fit a length of 4 m instead of 3 m, keeping the magnetic field value at 5 T. The relative luminosity loss in this case is about 14%: particles start to be deflected before QD0 and the number of emitted photons changes in the QD0 too, as can be seen in Fig. 4.

As a final check we verify that the beam distributions at the IP are increased due to ISR. The CLIC nominal beam with 1% linear energy spread has been considered in all these simulations. Figure 5 shows the horizontal and vertical beam distributions at IP, the emission of ISR due to the CLIC BDS increases the IP spot sizes in both planes, while the solenoid field act only on the vertical beam distribution, as expected.

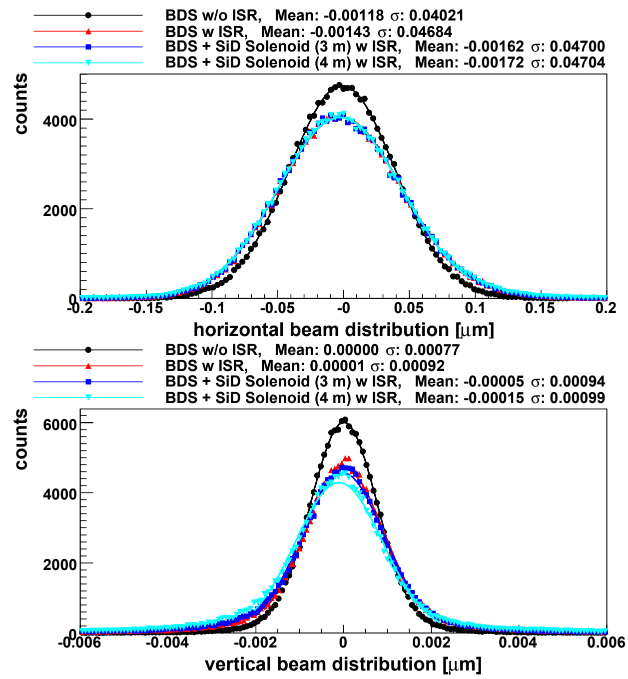

Figure 5: Beam distribution at the IP. For each of the case described in the text the mean and σ coming from the fit (drawn on the plot) are shown too.

CONCLUSION

The emission of incoherent synchrotron radiation limits the luminosity in a TeV linear collider. We have reviewed and studied the ISR effects in the CLIC-BDS and the IP solenoid. We have written a tracking program which takes into account the IP solenoid magnetic field and its overlap with the final magnets of the FFS. We found that the emission of ISR due to the CLIC BDS lattice at 3 TeV and $L^* =$ 3.5 m results in a luminosity loss of about 24%. When the magnetic field of IP solenoid is added the loss further increases between [2-14]%, according the IP Solenoid magnetic field strength and length.

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